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THE SCIENCE OF RELIABILITY

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THE SCIENCE OF RELIABILITY

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With the advent of progress, engineering design is bound to become more and more complicated and involved. Not only that, but the requirements imposed on its criteria of quality, for greater trouble-free operation and higher precision, wearability, temperature resistance, etc., will steadily increase.

Modern instrumentation, apparatus, machinery, assemblies, automatic production lines, composite equipment, plants, and facilities are all examples of complex systems. They are composed of a set of inter-dependent and inter-acting components and elements. Faulty operation and lack of support from any one of the components can lead to stoppage or breakdown of the machinery, which always involves loss of time and materials.

It is quite apparent that the problem of ensuring reliability of operation of complex systems is one of the most difficult to face in science and engineering. In recent years the scientific and engineering problems connected with the guaranteeing of proper operation of complex assemblies have been collated and generalized in a probability-statistical criterion of quality, namely reliability. In correspondence with the currently adopted terminology, reliability is the probability of trouble-free operation of any technological aggregate (equipment or industrial products) for a specified period of time and under specifically stated conditions, which then characterize the quality of that object.

At the Twentieth and Twenty-first Congresses of the CPSU, and at the June (1959) and July (1960) Plenums of the Central Committee, special consideration was given to the problems of raising the quality of industrial products. At the July 1960 Plenum it was pointed out in a number of proclamations that the solution of the problem of reliability is a top-priority goal and is the universal concern of the entire country.

The Factor of Technical Progress

The concept of reliability involves a number of qualitative

criteria, which are of overwhelming importance as far as the functional capabilities of various technological aggregates are concerned. The most general criteria characterizing the reliability of most types of machinery, apparatus, and instrumentation is the uniformity of wear of their principal working components. Even wear is achieved through uniform hardness of all parts, but this is not always economically convenient and is frequently unattainable on engineering grounds because in a number of instances increasing the strength of certain parts means having to ensure the necessary rigidity of construction.

In these cases it is more appropriate to provide for the controlled replacement of worn parts in order to guarantee optimum longevity of the machinery, apparatus, or instrumentation; this provision must be made not only on the basis of physical wear, but also hypothetical wear, as derived from engineering-economical analysis.

In addition to wear from dynamical influences on the material of the working components, the reliability of industrial aggregates depends also on their aging, in other words changes in chemical composition, structure, and physical-mechanical properties of the materials with the passage of time. Under the influence of abrupt fluctuations in temperature, shocks, shaking, or vibration the reliability of the structure can become lowered due to the shifting of stationary components, changes in the play of moving parts, or mechanisms being thrown out of balance, resulting in their regulation failure or breakdown. Also affecting reliability are changes in the remnant strain and hysteresis during the course of operation.

The fundamental criterion of reliability in the majority of machines is the maximum utilization of their capabilities for minimum expenditure in maintenance. In electrical, hydraulic, gas, thermal, and cooling systems a decisive factor in reliability is found in the continuous operation of the raw material supply. In transportation the usual criteria for reliability are the safety factor and adherence to the timetable. The reliability of electrical, pneumatic, and hydraulic equipment is characterized by its safety factor under various operating conditions; the reliability of inspection-measurement instrumentation and computers lies in the precision of the readings.

In different branches of science the engineering essence of the reliability problem is different. In power engineering, for instance, the primary criterion is the continuous operation of those components which consume electric energy, given a stabilized frequency and potential and high power factor. The continuous generation of electric power in modern thermal power plants depends on many factors, beginning with the manufacturing quality of the water and fuel. Boilers, which develop steam with high parameters, are very sensitive not only to the total salt content of the water used but also to the presence of isolated components, particularly the hard-water inducing salts. They give rise to the formation of encrustation on the heating walls and suffer large temperature potentials.

The methods of chemical water purification applied to power plants without automation do not guarantee sufficiently high quality for the boiler water. This substantially reduces the reliability of the boilers.

The mechanization and automation of fuel manufacture and supply is far behind the automation of the combustion processes in boilers, which in a many-sectioned system causes the entire boiler turbine section to be unreliable.

The continuous operation of electrical equipment depends to a great extend also on the reliability of the regulating systems, transformers, transmission lines, and networks. Their reliability depends on the stability of the power plant and transmission line equipment, which is exposed to large dynamic and thermal overloading upon short circuiting or excessive voltage loading of the atmosphere or commutation type. The high towers of several hundred-kilovolt voltage switches are subjected upon short circuiting to tremendous shocks, capable of demolishing the equipment. At the scientific research institutes working on the development of switches and at manufacturing enterprises such strenuous tests are not imposed because of the lack of necessary power and high-test equipment. And this fosters the great shortcomings in the utilization of our power systems

Weather disturbances on wiring, insulation, and the supporting towers of cross-country high-tension lines, particularly under ice and frost conditions, are frequently the cause of disruptions in the transmission lines, and lightning discharges give rise to breakdown of transformer insulations. This leads to serious failures and emergency situations.

Moreover, not enough has been done on the incorporation of discharge facilities to permit the protection of insulation against breakdown. The application of a system of automatic protection and regulation for the rapid pinpointing of emergency situations, as well as apparatus for remote control, remote warning, and remote measurement, which systems have already been developed at Mosenekgo [Moscow Power Administration?] with 96-99% efficiency, have not been worked into other power systems to the degree that they should. Over-all automation and remote-control mechanization of power-systems -- the only real way to step up the reliability of the country's electrification -- is still in a very slow stage of growth.

In metallurgy, the reliability of the basic aggregates rests mainly in the realiability of the auxiliary equipment. Breakdown in the operation of the charging device thus frequently disrupts the normal functioning of blast furnaces. There have been instances when the unreliable operation of automatic lift cutoff devices has led to the cables breaking and the skips dropping. Failure in the operation of terminal lever switches have been the cause of breakdowns in the traverse and blocks of casting and ladle cranes, dropping of the bucket containing the molten metal, breakage of forms, fractures in the shafts and gears, and breakage of the cables of bridge cranes.

In the chemical industry, insufficient reliability of the equipment not only cuts down on its efficiency and on the quality of the product, but often leads to accidents and production stoppage. Increased wear of the equipment under the action of aggressive media at high temperatures and pressures creates the danger of leakage of toxic, hot,

or explosive products through pump and compressor gaskets, armature packings, and the joints of apparatus and machinery with tubing of one sort or another.

In the present state it is impossible to detect leakages because of the lack of dependable warning and the imperfection of the control mechanisms, particularly the shutoff accessories. In the meantime, automation, which is the best means of ensuring uninterrupted operation and high production quality, is extremely deficient in its development within the chemical industry.

In chemical plants any kind of trouble in any piece of equipment along the production line will cause disruption of the technological process along the entire line and brings about interrupted production. This leads to excessive damage and losses. Emergency stoppage for even a single day of any one of the links in the complex machinery and apparatus of a high-efficiency aggregate for the production of viscose rayon fiber, given a cost of 1.6 percent of the cost of the entire factory, will induce losses to the extent of 5 percent of the cost of the aggregate, or 0.08 percent of the total cost of the factory.

Insufficient reliability in many agricultural machines is often one of the reasons for extension of the period of time required to sow and harvest. The operation of machinery under rigorous field conditions with large overloading, vibration, shock, and twisting and bending demands high durability and good protection against abrasive wear and corrosive failure. Failure of the materials used to bear up under these conditions will abruptly diminish the reliability of the machinery, even if its design and construction are the very best. This refers first and foremost to the working components that are subjected to particularly rapid wear. Treatment for the purpose of strengthening is utilized far too little. Self-sharpening plowshares are not being manufactured. Lacquer coatings are inadequate. All this leads to a low seasonal average output of the machinery and very high losses due to replacement and broken parts.

In the machine-building industry, the reliable operation of equipment not only predetermines what the quality of the products will be, but is also the main determinant of efficiency of its over-all automation. The great majority of the producing mechanism in industry are set in motion by asynchronous electric motors with a power ranging from 0.6 to 100 kv. Such motors are estimated to number more than 12 million in the national economy of the USSR, with a total power consumption greater than 70 million kilowatts. They require about 40 percent of the total electrical power that is developed in the country. The period of service of these motors, however, is small: more than 20% of them are replaced after three or four years. About 90 percent of the motors go out of commission from impairment of the windings. Consequently, in many mining enterprises whole plants are set up for the overhauling of the motors for mine transporting equipment.

Many of the shortcomings in the operation of electrically powered driving devices are caused by wear of the contact equipment. The fully guaranteed mechanical wearability of Soviet a.c. switches lies between the limits of 5-10 million operations instead of the 30 million of some

countries. Actually, though, the average number of operations is about 20 percent of what is guaranteed. The main reason for the premature failure of switches is breakdown due to imperfections in their manufacture. Partial breakdowns and unevenness in the operation of track and terminal switches account for the tremendous number of accidents and failures of various industrial equipment.

The reliability of machinery suffers from poor quality in the bearings and insufficient protection against abrasive wear and overheating. The situation with regard to lubricating materials is completely unfavorable. The assortment of these from which one may choose is altogether too limited, and the quality is low. The marketed oils and greases do not meet the requirements of modern engineering needs, they lead to accidental breakdown and premature wear, and retard the further development of the machinery. Stable high-viscosity lubricants and lubricants with anti-freeze additives suitable for the conditions of the country's northermost regions are nonexistent. All this greatly diminshes the longevity of the machinery.

Increased reliability of the elements, components, and entire units of engineering equipment still does not solve the problem of overall reliability, which relates to the single universal system of automatic regulation. The application of low-sensitivity, low-response, or unstable transmitters does not ensure precise information concerning the state and fluctuations of the parameters to be controlled. Inability to withstand mechanical, thermal, chemical, or radiation influences of the medium will quickly deteriorate the reproducing organs of the transmitters. The reliability of many transmitters is one of the main factors accounting for breakdown in the function of automatic control systems.

Generalize Experience, Broaden Theory

Despite the tremendous losses suffered by the national economy as the result of accidents and breakdown in the operation of industrial equipment, the problem of reliability fails to be accorded the proper attention. Allowance for the premature failure of machinery, apparatus, and instrumentation is poorly realized, and there is no generalization and systematic analysis of reclamations on a statewide basis.

Those organizations established to study the results of industrial testing and commercial experimentation are most often unequipped to answer how reliable our most important types of industrial equipment are, why it frequently is lower than for the analogous non-Soviet type, or what measures are necessary in order to eradicate this below-normal situation.

Moreover, in our planned socialist economy the problem readily attracts due attention, especially since experimentation to centralize the separate factor of unreliability is already under way in a number of our organizations and institutes. Thus in the State Committee on Electronics of the Council of Ministers USSR many industrial laboratories are studying ways and means to increase the reliability of electronic components.

Mosenergo has a centralized failure inspectorate, which records

and traces all cases of failure in the Moscow combined power system, and the inspectorate of Glavenergo (Main Power Administration,) of Gosplan USSR generalizes and analyzes data on the failure of power systems on a general statewide basis. Clearly, this experience can be extended to other branches of the economy.

It would seem unnecessary to demonstrate the utility of scientific research directed toward ensuring high reliability in Soviet equipment. Hardly to be disputed is the possibility and exigency of forming a new branch of science to deal with reliability, which, on the basis of the systematization and generalization of practical industrial experience and utilization of the material resources in the various branches of the national economy, could develop a theory and yield specific recommendations for a procedure to increase the reliability of many engineering systems.

But in order to augment the reliability of machinery, apparatus, and instrumentation it is necessary first of all to establish scientific principles and engineering standards by which the science of ensuring reliability might be created. Always, whenever cause and effect connections between effects cannot be established and the effects themselves are on a large scale, we are then concerned with so-called chance quantities. The laws governing them constitute the study of mathematical statistics and probability.

The criterion of reliability of a complex technological component depends on an aggregate of interconnected factors, the chance quantities, and is a typical statistical parameter. All measures taken to raise reliability should therefore be based foremost on statistical analysis of the influencing factors at all stages of development — in production, in transport, storage, and in utilization of the components.

On the basis of mathematical statistics and the mathematical theory of probability the beginnings of a mathematical theory of reliability have already made their appearance. There is an extensive Soviet and foreign literature covering this problem.

During the last few years six thorough and numerously attended symposiums on the problem of reliability in electronics have been held in the US with the USSR participating; considerable information is available in print as a result. The American Institute of Radio Engineers (IRE) regularly publishes special technical reports, in addendum to their proceedings, on the increase of reliability in electronic equipment.

Seminars and scientific conferences have met in the USSR in recent times to discuss raising the level of qualification of engineers and technicians working in the area of reliability in the electronics industry. In January 1961 a conference on reliability in mechanical engineering and instrument design was held in Minsk.

All this, however, is only the beginning of the extensive work that must be done on a scientific basis. Of course the reliability of every engineering component begins to build up from the moment of inception and depends on many factors requiring effective systematic control from the very beginning design and continuing throughout all

stages of development, production, and utilization.

For this it is first of all necessary to make a valid critical evaluation of the technological notions that arise in the exploratory stage, with a first appraisal. We need to develop research on a wide front, which will make it possible to find the most promising solutions. Foreign firms, for instance, spare no effort in research, and their expenditures for this effort far exceeds our own. This is obviously a good thing.

The framework of research determines technological progress and should therefore be greater on our part in this area of knowledge than on the part of the capitalist countries. In several instances the apportionment of research work to many small organizations limits the possiblity of a unified development along parallel lines of a number of a number of engineering principles and modifications of a single trend. This in turn restricts the perspective of mathematicians and economists, the application of computer and analog machinery for the verification of the theoretical hypotheses, and fails to promote rapid performance of calculations and comparative analyses of the principles being worked out or their embodiment in design.

Superficial scientific research often generates unreliable equipment. Theoretical and experimental work on all the criteria of reliability needs to be considerably expanded. With the design of new machinery, apparatus, and instrumentation we need proper allowance for all the possible conditions under which they are utilized, and this should find its reflection in engineering design. The optimum requirements for reliability should be worked out by the specialized scientific research institutes in conjunction with the manufacturing enterprises, taking into account the engineering and economic feasibilities. We need to probe deeper in the study of the influence of engineering on reliability and machine capabilities.

The consolidation of effort in the existing and newly created scientific research institutes is directed toward obviating these faults. For the guarantee of high reliability in conceived engineering components a serious checking and reviewing of the scientific literature is necessary, with the idea of making a start toward ensuring qualified control in the application of advanced theories and analytic methods that foresee and eliminate subsequent failures.

In order to ensure stability and a high reliability of the components we need to equip our laboratories with modern experimental means. Scientific-instrumentation design is far from satisfying the requirements of our national economy and the needs of science. Because of the sad state of affairs in the nomenclature of high precision scientific instruments, the quality of the experimental investigations is lowered and the significance of the results obtained becomes dubious. If we are to speed up the development of scientific-instrument design we must first of all invest it with a nomenclature in correspondence with the types of institutes concerned and formulate categories by which these instruments and experimental apparatus should be developed.

It is time now to set forth a rigid schedule for the material and

engineering outfitting of our scientific research organizations.

But the cause of many of the shortcomings in scientific work is buried not only in the fact that the institutes are unable to receive in good time the measurement and control instruments and laboratory furnishings already appropriated and produced by industry, but also in the poor supply of high quality materials, auxiliary articles (laboratory glass, metals of the required type, ceramic, insulation material, semiconductor instruments, cables, tubing, and other accessories).

Approaches to Increased Reliability

Very often the reason for functional unreliability in machinery is found in the unequal service lifetimes of the various systems, assemblies, and components. As a result of this, the idle time of a machine frequently exceeds its actual running time and sums of money are spent on overhaul which sometimes are more than ten times greater than the cost of the machine. Thus about 30 percent of all the tractors, a considerable number of motor vehicles, as many as 25 percent of the construction machinery are all idle. The diesel engines put out by the plant in Minsk for dump trucks and 25-ton steam shovels operate for 1000 to 1200 hours, i.e., three to four months, before major repairs are necessary. The electric motors of vibrators work for 200-300 hours, grease pumps used in hydraulic installations have a period of service equal to 1000 hours, and many components of agricultural machinery do not hold up under the requirements of a single season.

We need to have methods for calculating designs for optimum lifetime with economically reasonable periods of service for both the individual components and parts subjected to greatest wear and tear and the design as a whole. The design should ensure self-regulation and compensation for wear and bring the surface and volume strengths closer together. Of great importance is the application of modern methods of tightening the most heavily loaded components by chrome plating and wearproof seam welding, drilling, and cold working.

Repairs on large scale, mass-produced machinery with the application of noncritical systems, in particular in the motor-vehicle industry, lead to sharp curtailment of reliability and remaking of the damaged parts. The amount and periodicity of repairs should be scheduled in design and construction. It is necessary here to make provision for inspection and the opportunity for efficient and rapid replacement of worn parts. The problem of repairs should be kept constantly before the research, design, and planning groups required to furnish the necessary recommendations and scientifically based norms.

Very little attention is alloted to the guarantee of high design reliability in the development stages of engineering components. It is important that the problems of reliability always be before planning experts, a plan that should be accomplished by proper administrative control. Many of these potential situations could be worked out and realized in the near future. In particular, factory engineering norms are already being assembled, new standards are being created. The

Committee on Standards, Measures, and Measuring Instruments should not approve standards without reliability criteria. For the purpose of speeding up the process of design and the guarantee of its continuity with minimum expenditure of effort, it is necessary that the planning and design bureaus be furnished with up-to-date planning engineering methods and computer machinery for analoging components.

The design reliability achieved under laboratory conditions and during the course of planning and design still falls short of guaranteeing the true reliability of the article in its actual utilization. Many design nuances not accounted for in the blueprints are detected in the production of the prototype. Exhaustive investigation of the prototype under critical conditions and in unfavorable external situations, using modern experimental setups, unmasks a number of design deficiencies, the elimination of which would raise the level of reliability. Subsequent suitable tests of both the individual parts and components and of the construction as a whole on special equipment will make it possible to expose new factors of design reliability. Only after elimination of these can a specimen for the final stage of construction be made.

The new model should be checked out and finished completely at the factory prior to the beginning of regular production, so that not only its working capabilities and limitations be checked out, but also its reliability over prolonged operation. By breaking down the specimens ready for production into components and individual units, the long-term dependability of the entire construction can be checked out experimentally in relatively short periods of time and well before the technological article as a whole will be ready. Taking this view of the situation, the final stage of design can be reliably executed on the prototype specimen before changing over to regular production.

Design reliability ties in intimately with production reliability, which ensures the over-all reliability of the products in the stages of industrial manufacture. Maintaining the specified characteristics in the new engineering component in its manufacturing stage means stabilized quality of the raw material, strict observation of the prescribed conditions of processing and engineering procedures.

Stabilization of the raw material under normal conditions should be guaranteed by its suppliers. However, in order to provide for the possibility of undesirable elements getting into the production process, control and selection of the material are necessary, which is most reliably ensured through express analysis on inspection equipment and automatic, continuous operation selectors. For this the most suitable methods of inspection and analysis are based on the application of ultrasonic absorption and reflection, infrared, visible, ultraviolet, x-ray, and nuclear radiations, magnetic flaw detection principles, and other up-to-date procedures. A highly effective approach is the polarographic method, which is distinguished by universality and high precision. Automatic selection according to size and quality of the materials introduces order into the very beginning of the technological process.

Observation of the specified requirements and predesign for

stoppage in the production process are accomplished most reliably by the application of passive automatic inspection directly in the machinery and processing aggregates; this is instigated by the use of contactless (not coming in touch with the article) pneumatic and electric transmitters acting on the functional mechanisms of the control system. Another possibility in this connection is quality control that can also be effected during the production process by magnetic, induction, radioactive, and other nondestructive testing methods.

Of exceedingly great importance for the protection of the consumer from unreliable machinery, equipment, and instrumentation is the perfection of test facilities used to check out large-scale, mass-produced articles as they emerge from production. Cumbersome test stands, glutted with instrumentation, take away much time for the inspection and analysis of their readings. They should be replaced by high speed automatic test machines and analyzers with computer equipment capable of yielding finished test results from all the control readings in standard form with clearly marked deviations from the norm, fixing them within the engineering ratings. They will show up defects in the components as they interact and any deficient quality of the manufactured articles in assembly, which will then serve as a basis for their rejection prior to regular production.

With the inspection process set up in this way, production reliability will be detected during production and not in use by the customer. This will rid the national economy of great losses and failures caused by malfunction and premature failure of machinery, apparatus, and instrumentation, as well as serious accidents and emergency situations. This inspection technique we have begun to realize in part, much is in the stage of development, but its embodiment in practice is proceeding extremely sluggishly. The production of reliable components must be set aright and direct responsibility conferred for the application of the newest engineering methods of inspection, ensuring the stepping up of reliability in industrial products; such is the responsibility of the Sovnarkhozes (Councils of National Economy), to evaluate the work of manufacturers not only in gross production, but also in the quality of the latter.

If the design and production reliability of engineering components is high, it can still be lowered considerably by improper storage, transportation, and use, which come under the heading of utilization reliability. Storage in improperly outfitted sites, exposure to dust, rain, and snow, harmful handling and transportation with jarring and shock, if they do not cause total breakage and destruction, at least cut down on the utilization reliability of the equipment.

Raising the utilization reliability of complex pieces of equipment, especially automatic instruments and apparatus composed of many assemblies, requires the application of only specialized equipment designed for use under given conditions. Their specifications should completely withstand the demands put on them. Toward this end, all electrical and instrument articles necessary for the assembly of the finished equipment and requiring special handling should be exposed, and should be designed to function under approved engineering conditions.

The reliability of engineering components in all stages of their manufacture and utilization is determined by qualified personnel. The scientist, engineer, designer, and planner, in addition to having knowledge of his own specialty, must be up on the latest achievements of physics, chemistry, physical chemistry, chemical physics, mechanics, aerodynamics, electrical engineering, and electronics. Without this knowledge the production of machinery, mechanisms, and instruments is inconceivable. Many important discoveries and inventions are now being made with interdisciplinary cooperation. Quite often insufficient knowledge of mathematics, economics, and modern engineering, as well as the relatively narrow specialization of designers and planners impede the development of reliable and economically efficient designs.

It is therefore essential that we improve the system for training scientific, engineering, technical, and working groups, ensuring their acquisition of the necessary knowledge on the level of modern achievements of science and technology. It is very important to increase systematically the qualification of personnel by setting up courses, seminars, lectures, exhibits, better organization of scientific and technical information and literature, and the organization of special courses in the theory of reliability in machinery, apparatus, and instrumentation. Instruction on the special discipline of reliability in equipment needs to be incorporated into our advanced and intermediate scientific institutions.

Textbooks and manuals need to be written, published, and widely distributed for variously qualified workers responsible for increasing the reliability of industrial articles. It is urgent that we see an extensive publication of the materials from the various conferences on reliability, the publication of a special journal on reliability after the pattern of the international journal Iznos (Wear).

Success in the improvement of reliability can be achieved only with an effective system of regular collation of information, due allowance for operative failures and premature breakdown of machinery, apparatus, and instrumentation, analysis of the causes and development of clearly defined recommendations for their elimination, and active inspection in order to make sure that the adopted recommendations are carried out.

The increase of reliability in machinery, apparatus, and instrumentation is the responsible problem not only of scientific, designers, technicians, and workers in the departments devoted to technical inspection, but to no lesser a degree the workers themselves. They are the ones who are directly concerned with the value of the materials produced, in their hands is the life and power of the industrial product. The responsible awareness of all workers must be raised in the constant battle for higher production quality of machinery, apparatus, and instrumentation and their zealous commercial utilization.

Caption to photograph /not reproduced here/: As part of the accelerated pace of the Seven-Year Plan the Kursk Synthetic Fiber Plant

incorporates all the newest procedures and machinery for the production of lavsan [Soviet developed synthetic fiber]. The plant personnel compete to bring the plant up to early full production capacity. In the photo is shown chemical spinning machinery for the production of lavsan. The operator is Svetlana Potapova. Photo by V. Polunin.

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